The debate on flexibility of environmental regulations, innovation capabilities and financial performance – A novel use of DEA

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ABSTRACT

Operational research models have been employed to understand development issues associated with environmental sustainability. This article describes a novel application of Data Envelopment Analysis (DEA) to help extend a specific debate in the literature on Porter's hypothesis in environmental policy. The debate deals with the impact of flexibility of regulations on the relationship between innovation capabilities on financial performance in organisations. Using the resource based view of a firm, we hypothesise that relationship between innovation capabilities and financial performance in firms depends on how flexible or inflexible environmental regulations are. We apply DEA to capture the flexibility of environmental regulations. Our results indicate that innovation capabilities significantly influence financial performance of firms if firms feel that the environmental regulations they face are flexible and offer more freedom in meeting the requirements of regulations. On the other hand, corporations that feel that they face more inflexible regulations are not so effective in improving their financial performance with their innovation capabilities.

Keywords: Data envelopment analysis, Porter's hypothesis, flexibility, innovation, performance.

1 Introduction

Operational research tools have long been employed usefully in order to understand policy issues related to environmental sustainability. In this research, we apply data envelopment analysis (DEA) to help generate new insights on the on-going debate on the role of innovation in the context of Porter's hypothesis. Porter's hypothesis deals with the win-win possibility that firms can adhere to the requirements of environmental regulations and at the same time improve their own performance (Porter, 1991; Porter and van der Linde, 1995;

Shrivastava, 1995). This is in contrast to a traditional view that regulations are harmful for private businesses as firms need to spend extra money to deal with regulations.

Environmental regulations are used by governments across the world to regulate firms for sustainable development. However, the mechanisms by which the regulations can be made more efficient, which form the core of Porter's hypothesis, are still under debate (Orlitzky et al., 2003; Sitkin and Bies, 1994). Porter's hypothesis highlights that firms with improved environmental performance (in meeting the requirements of regulations) can simultaneously improve their financial performance. This argument is based on the notion that environmental regulations provide enough flexibility to firms to develop new products and processes and that firms have innovation capabilities to be able to take advantage of the flexibility of regulations (Porter and van der Linde, 1995). Some previous studies have shown that more flexible regulations result in better environmental performance in firms (Majumdar and Marcus, 2001). Specifically, the issue of how individual firms can use regulatory requirements to improve their own performance has been analysed in several studies (e.g., Pethig, 1976; Shrivastava, 1995). However, there seems to be no study that empirically analyses the role of regulatory design and firm innovation within a single framework. Our study reported here is motivated by this research gap. Our study involves an innovative application of DEA to analyse flexibility of regulations.

Drawing on the resource-based view of the firm (Barney, 1991), we argue in this paper that the influence of innovation capabilities on financial performance in firms is affected by the level of flexibility in environmental regulations. That is, if firms face more flexible regulations that focus on outcomes rather than on processes, they are able to use their innovation capabilities to achieve the desired results in the most cost effective way. This, in turn, impacts positively both on their environmental performance and financial performance. We test these propositions using primary survey data of firms in the UK. A key feature of our analysis is the use of Data Envelopment Analysis (DEA) for capturing, for the first time, the flexibility of environmental regulations.

This paper makes at least two contributions to the literature. There are only very few studies that have evaluated the level of flexibility in environmental regulations; our innovative use of DEA to assess the level of flexibility is a significant contribution to this study. Up until now, to our knowledge, there is no study in the literature that has tested the level of flexibility of regulations on the relationship between innovation capabilities and financial performance (FP) in firms. This is another contribution.

2 Literature review

2.1 DEA and its applications in environmental sustainability analysis

DEA is a mathematical programming technique commonly used for estimating the efficiency with which different decision-making units or DMUs (which can be schools, hospitals, retailers, etc.) are able to convert their resources (usually called inputs in the DEA literature) to good performance - usually called outputs (Cooper et al., 2007; Ramanathan, 2003). It was originally developed in 1978 when a very interesting transformation was used to change a fractional programming problem into a linear programming problem (Charnes et al., 1978). Because of its intuitive appeal, this technique has received the attention of a number of researchers, both in terms of technique development (e.g., returns to scale analysis - Banker et al. 1984, cross-efficiency - Doyle and Green 1994, super efficiency - Andersen and Petersen 1993, network DEA - Kao 2014, multiplicative and additive versions of DEA - Charnes et al. 1985, imprecise DEA - Zhu 2003, treatment of undesirable outputs - Scheel 2001, and many more) and in terms of its applications (e.g., schools, universities, industry sectors, hospitals, retailers, banks, for deriving weights from pairwise comparison matrices - Ramanathan 2006, for ranking problems - Adler et al. 2002, for multiple-criteria decision making -Joro et al. 1998, new product development - Swink et al. 2006, and many more). A number of reviews of DEA have been regularly published in academic journals (e.g., Seiford and Thrall, 1990; Angulo-Meza and Lins, 2002; Cook et al., 2009; Kao, 2014).

DEA has found a number of interesting and innovative applications in the context of environmental sustainability analysis, including eco-efficiency analysis of power plants (Korhonen and Luptacik, 2004), measurement of ecological efficiency (Dyckhoff and Allen, 2001), eco-efficiency of productions (Kuosmanen Kortelainen, 2005), transport efficiency (Ramanathan, 2000), and environmental assessment in the petroleum sector (Suyoshi and Goto, 2012a).

Zhou el al. (2006) have modelled environmental performance of 30 OECD countries using a slack-based environmental DEA model. They have developed two different efficiency measures. One is a composite index with higher discriminating power to test economic-environmental performance, while the other measured the impact of environmental regulations using ratio of efficiency scores with and without undesirable outputs in the DEA model. Zhou et al. (2007) used non-radial DEA approach to measure environmental performance of 26 OECD countries and showed that non-radial measures have higher discriminating power than radial ones in comparing environmental performance of nations.

Zhou et al. (2012) have used non-radial DEA to analyse energy and carbon emissions of several countries and found that OCED countries per better carbon emission performace than their non-OECD counterparts. Recently, Wang et al. (2016) have used a DEA-based optimization model to show the superiority of market-based carbon emission trading schemes with command-and-control regulatory policies in China.

In a related strand of using DEA for environmental analysis, Sueyoshi and Goto (2011) proposed a new use of DEA with Discriminant Analysis (DA) and Strong Complementary Slackness Condition. The authors claimed that the new approach could reduce the inefficiency of conventional DEA. Following this suggestion of the new approach, Sueyoshi and Goto (2012b) employed combine use of DEA and DEA-DA to energy firms to determine the efficiency-based ranks.

Chen et al. (2012) have used a two-stage network DEA model to evaluate various sustainable product designs. Their two stage approach used an industrial design module in the first stage with engineering specifications as inputs and product attributes as intermediates (similar to a Quality Function Deployment approach), while the second stage is a bio-design module with product attributes as inputs and environmental performance as outputs. Using data from major carlines, the authors have shown that sustainable design does not require compromise between traditional and environmental attributes. A similar network DEA approach has been used by Guan and Chen (2012) to understand drivers of National Innovation Systems. Their two-stage network DEA used an upstream knowledge production process in Stage 1 and a downstream knowledge commercialization process in Stage 2. They then combined the results of DEA with Partial Least Squares regression model to examine the effects of various policies on innovation efficiency. This study was preceded by a study by the same authors where a similar two-stage network DEA was used to understand innovation production in Chinese regions (Guan and Chen, 2010).

Lee and Saen (2012) have introduced a novel dual-factor DEA model for measuring corporate sustainability management of ten Korean electronics companies. Their DEA model used two traditional inputs (direct expenses and personal costs), a traditional output (cost savings) and a duel-role factor (viz. donations for tax benefits) which could be interpreted both as an output and as an input. Chang et al. (2013) have compared 311 firms belonging to 16 industrial sectors in terms of sustainability performance using a traditional DEA model. The outputs of their DEA model are three measures each for economic, environmental and social dimensions. Desired goals, which are constant values, are used as the inputs.

A detailed review of the applications of DEA in the fields of energy and environment has been provided by Zhou et al. (2008).

2.2 Flexibility of environmental regulations, innovation and performance

The impact of environmental regulations on innovation and performance is a widely researched topic (e.g., Chang, 2011; Darnall, 2009; Osuji, 2011; Rothwell, 1992). Traditionally, environmental regulations have been considered as burdens on businesses since pollution abatement and restrictions on the use of certain materials raises the cost of operations, thereby reducing profitability and productivity (Christiansen and Haveman 1981). However, Porter (1991) suggested that environmental regulations might in fact be beneficial for businesses. This win-win argument of Porter's hypothesis highlights that, if regulations are designed to provide flexibility to firms in meeting their demands and if firms have innovation capabilities, then regulations could improve financial performance of firms. This improvement is possible because innovations such as leaner manufacturing practices and more efficient energy and resource use, not only reduce manufacturing costs but also improve financial performance. A number of previous studies (Orlitzky et al., 2003) have focussed on the link between environmental performance and financial performance of firms, which is the primary area of Porter's hypothesis. However, there are not many studies that considered other important elements of the hypothesis, namely the level of flexibility of regulations and the level of innovation capabilities in firms. Our study is aimed at filling this research gap.

2.2.1 Flexible and inflexible environmental regulations

The literature on environmental regulations has highlighted the impact of flexible and inflexible regulations. For example, direct regulations where the government imposes a legally enforceable standard are not considered to be helpful to innovation in firms compared to those regulations that provide economic incentives and disincentives (Rothwell, 1992). Economic incentives use market forces for efficient allocation of resources and hence encourage firms to use their innovation capabilities much better. Majumdar and Marcus (2001) have highlighted that more flexible approaches to regulations enhance performance by stimulating entrepreneurship and risk taking (Marcus, 1988; Strebel, 1987). On the other hand, excessive procedures and rule-centred regulations - such as the direct regulations- stifle innovation (Eisenhardt, 1989 as highlighted by Majumdar and Marcus, 2001).

2.2.2 Theoretical underpinnings – the Resource Based View (RBV) of a firm

The resource-based view (RBV) has been suggested in the literature to understand the influence of innovation on the performance of firms. This theory was originally developed to help understand how a firm can exploit its internal resources for sustained competitive advantages (Yang and Konrad, 2011; Hitt et al., 2016). The RBV recognises that the basis for a competitive advantage of an organisation lies primarily on the application of the bundle of valuable resources at the firm's disposal (Rumelt, 1984). Thus, if an external pressure (flexible regulation here) provides opportunities to exploit internal capabilities innovatively, organisations will utilise them to their competitive advantage. For example, a more flexible regulation can encourage firms to move from simple compliances to more intelligent integration (Kelman, 1961). When firms are faced with flexible situations, those with superior innovation capabilities tend to exploit their available resources better through entrepreneurship and risk taking (Marcus, 1988; Strebel, 1987). Interestingly, literature also has studies highlighting how creativity is stifled when firms are faced with inflexible rules, excessive procedures and a rule-centered culture (Eisenhardt, 1989).

Using RBV, Russo and Fouts (1997) have highlighted that organisations should be innovative in their approach to regulations as more flexible regulations would allow them to tailor their responses to their own needs and to seek innovative solutions to meeting their responsibilities. The literature has argued that flexible regulations are more likely to induce better economic performance (Majumdar and Marcus, 2001; Porter and van der Linde, 1995). More flexible regulations will focus on outcomes, set challenging performance goals and provide sufficient time for companies to engage in innovative activity (Majumdar and Marcus, 2001; Porter and van der Linde, 1995). Similar observations can also be found from the extant economics literature. Using data on 1948 retail stores in India, Amin (2009) has found that flexible labour regulations had a strong positive effect on job creation. In another study, Almeida and Carneiro (2009) found that stricter regulations have led to higher unemployment in Brazilian firms.

There have been some studies that have accounted for one or the other of the requirements of Porter hypothesis: the innovation capabilities and resources of firms was considered by studies such as Klassen and Whybark (1999) and Christmann (2000) whilst the importance of the nature of regulations under question was examined by Majumdar and Marcus (2001) and Crotty and Smith (2006). Studies by Brunnermeier and Cohen (2003) and Jaffe and Palmer (1997) have not considered whether the regulations in question allow scope for innovation. Though this gap has been identified using qualitative studies (e.g.,

Ramanathan et al., 2016), to our knowledge there has not yet been a quantitative study which accounts for the role of innovation capabilities and the nature of the regulation together. This study aims to fill this gap.

Thus, drawing on the resource based view and the previous literature, we propose the following hypotheses.

Hypothesis 1: *Innovation capabilities of firms are significant in achieving better financial performance when they face more flexible environmental regulations.*

Hypothesis 2: *When faced with relatively less flexible regulations, firms are not able to exploit their innovation capabilities to achieve superior financial performance.*

3 Sample selection and survey

A specialized questionnaire survey was conducted among manufacturing firms in the UK in order to collect primary data for this study. Nearly 2000 manufacturing firms in the UK were contacted in September 2009, but only 125 completed questionnaires were received in spite of reminders. Another 1000 firms were approached in February 2010, which resulted in 50 additional responses. After deleting unsatisfactory/non- responses, the final sample size was 131. As highlighted in previous studies (e.g. Harmon et al., 2002; Melnyk et al., 2003), such a low response rate is not uncommon in large scale survey research, and our response rate is comparable to other survey-based environmental management studies (e.g. Chiou et al., 2011; Kassinis and Soteriou, 2003; Green et al., 2012).

Student *t*-tests were used to check whether there were substantial differences between the two sets of samples. As no statistically significant difference for all questions in the questionnaire were found, the two waves of questionnaires were pooled together.

Our initial procedures involved testing for non-response bias and for common-method bias. Armstrong and Overton (1977) have suggested that non-response bias can be checked by comparing responses of late respondents with those of early respondents. As mentioned above, there were no statistically significant differences between the two waves of questionnaires. More tests were performed for checking non-response bias. Since the population of our sample was all manufacturing firms in the UK, we used data from Financial Analysis Made Easy (FAME) Database to get data for our population, and then tested whether there was a significant difference between the means of the 2008 turnover, 2008 cost of sales and 2008 total assets in our sample and that of the population. We found no statistically significant differences, confirming that non-response bias was not a serious problem with our survey.

We then tested for common method bias in our data by employing Harman's one factor test (Harman, 1967; Darnall et al., 2008). The procedure is to carry out a factor analysis of all the items of interest without using factor rotation methods. If all variables load on one factor, common method bias exists. In our case, a factor analysis resulted in more than one factor, implying that there is no common method bias.

4 Data Analysis

This study uses Data Envelopment Analysis (DEA), factor analysis and regression in order to test Hypotheses 1 and 2. DEA has been used to develop a measure of relative flexibility of environmental regulations. Factor analysis has been used to develop constructs for innovation and financial performance while regression has been used to test the significance of innovation on financial performance. We have used the number of employees as a control variable for size in the regression calculations. Regression was conducted using SPSS version 21.

4.1 Measures and scale development

Our scales and measures are drawn from previous academic and practitioner literatures. Financial performance has been measured using a variety of indicators in the previous literature: Return on Assets or Return on Equity (e.g., Agle et al., 1999; Berman et al., 1999), stock performance (e.g., Brammer and Millington, 2008), sales growth and market share (Eiadt et al., 2008; Darnall et al., 2008; Tanriverdi and Lee, 2008; Antoncic and Prodan, 2008). Darnall et al. (2008) have used sales growth market share for measuring business performance by asking respondents to respond using a five-point Likert type scale. We have used a similar approach in our study. Accordingly, financial performance in our study has been measured by self-evaluated measures of sales growth and improvement in market share.

In line with the UK and European Community Innovation survey (www.berr.gov.uk) (Robson and Kenchatt, 2010) and in similar previous research studies (e.g., Horbach, 2008, Pippel and Seefeld, 2016; Raymond et al., 2015), we have measured innovation activity using two measures: introduction of a new or significantly improved product (good or service) (product innovation) and development of a new or significantly innovative production process (process innovation).

Finally, we have captured flexibility and inflexibility of environmental regulations using previous literature (Rothwell, 1992; Majumdar and Marcus, 2001). Accordingly,

flexible regulations have been measured in terms of their ability to offer economic incentives, disincentives or penalties, and the ability to force integration of pollution control into production processes. On the other hand, stipulation of absolute thresholds of pollutants or specification standards, and forcing to use end-of-pipe equipment are used as measures of inflexible regulations.

Table 1 lists the measures and their literature sources used in this study. All the questions are self-evaluated measures using Likert-type scales (1-5).

Table 1: Measures used in this study and their literature sources

No.	Acronym	Item	Literature sources
		Flexible environmental regulations	
	Eregincen	Company faces environmental regulations that offer economic incentives	Majumdar and Marcus (2001), Rothwell (1992), Rugman and Verbeke (1998)
	Eregpen	Company faces environmental regulations which offer economic disincentives/penalties	
	Eregipc	Company faces environmental regulations which encourage integration of pollution control into production processes	
		Inflexible environmental regulations	
	Eregstand	Company faces environmental regulations which set standards/absolute thresholds	Majumdar and Marcus (2001), Rothwell (1992), Rugman and Verbeke (1998)
	Eregspec	Company faces environmental regulations which stipule specification standards	
	Eregeop	Company faces environmental regulations that can be met by buying end-of-pipe equipment	
		Innovation capabilities	
	Procinno	Company has developed several innovative processes in the last 5 years	UK and European Community Innovation survey (www.berr.gov.uk), Horbach (2008), Pippel and Seefeld (2016), Raymond et al. (2015), Robson and Kenchatt (2010)
	Prodinno	Company has developed several innovative products in the last 5 years	
		Financial performance	
	Sales	On an average, sales have been growing over the last 5 years	Antoncic and Prodan (2008), Darnall et al. (2008), Tanriverdi and Lee (2008)
	Markshare	On an average, company has increased its market share in the last 5 years	

Table 2 provides summary statistics for all the measures. This table reveals that, though the firms are operating within the same country (UK), they perceive the level of flexibility in regulations differently.

Table 2: Summary statistics for the measures in Table 1

	Maximum	Minimum	Average	Standard Deviation
Eregincen	5	1	2.63	1.22
Eregpen	5	1	3.11	1.21
Eregipc	5	1	3.33	1.26
Eregstand	5	1	3.90	1.09
Eregspec	5	1	2.93	1.20
Eregeop	5	1	2.46	0.99
Procinno	5	1	3.50	0.92
Prodinno	5	1	3.58	0.92
Sales	5	1	3.66	1.04
Markshare	5	1	3.53	0.95

4.2 DEA for computing scores on relative flexibility of environmental regulations

There is very limited literature that captured the flexibility of environmental regulations empirically. We are aware of only one study (Majumdar and Marcus, 2001) in this context. Majumdar and Marcus (2001) categorized regulations using their own judgement of regulations in various areas – solid waste, water and air regulations. For example, they categorized air regulations as inflexible and solid waste regulations as inflexible based on regulatory status in the US prior to 1993. However, such clear distinction is not possible in the last few years in the UK as some newer air pollution regulations – such as the European Union-wide greenhouse gas Emissions Trading Scheme Regulations 2003/05 and the Environmental Protection (Controls on Substances that Deplete the Ozone Layer) Regulations 1996 – can be classified as flexible regulations while earlier air pollution regulations are inflexible regulations. Hence, we have chosen to capture the relative flexibility of regulations from the eyes of our respondents using the survey. We then used these ratings to produce scores of flexibility of regulations using Data Envelopment Analysis (DEA).

In our analysis, DEA outputs are measures of flexibility of regulations (Eregincen, Eregpen and Eregipc), while DEA inputs are measures of inflexibility of regulations (Eregstand, Eregspec and Eregeop). Please note that this interpretation of outputs and inputs may not be consistent with the traditional use of DEA as a performance measurement tool but is acceptable as per the interpretation of DEA as a multi-criteria decision making tool (e.g.,

Joro et al., 1998; Bouyssou, 1999). When DEA is used as a multi-criteria decision making tool, the factors to be maximised are treated as outputs and the factors to be minimised are treated as inputs (Doyle and Green, 1993; Ramanathan, 2003; Stewart, 1996). In our analysis, we are interested in identifying relative flexibility such that high scores would mean face more degree (e.g., Eregincen, Eregpen and Eregipc) of flexible regulations and low scores would mean more degree (e.g., Eregstand, Eregspec and Eregeop) of inflexible regulations. Thus the emphasis of the DEA application is on capturing relative flexibility of regulations such that higher relative flexibility would mean more flexible regulations. The DEA literature has suggested that one way of classifying a factor as an output would be to check whether units recording higher performance in terms of that factor would be considered more efficient or not (Golany and Roll, 1989; Dyson et al., 2001; Ramanathan, 2003). As the goal of our DEA is to measure relative flexibility levels, factors contributing to flexibility are considered as outputs (factors to be maximised) while factors not contributing to flexibility are considered as inputs (factors to be minimised).

Table 3 provides a summary of DEA results. The relative flexibility scores range from 0.33 to 1. Thus, if the relative flexibility score is closer to 1 for a firm, it would mean that the firm perceived that the environmental regulations were more flexible from their point of view than inflexible regulations. Similarly, a relative flexibility score closer to zero would mean that the corresponding firm felt that it has faced more inflexible environmental regulations than flexible regulations. We used variable returns to scale DEA models as they measure pure efficiencies excluding the effects of scale (Cooper et al., 2007; Ramanathan, 2003).

Table 3: A summary of relative efficiency scores computed using DEA

Maximum	1
Minimum	0.33
Average	0.77
Standard Deviation	0.21

In order to facilitate further analysis on differing levels of flexibility of regulations, we categorized our respondent firms into two groups based on the DEA scores. The first group comprised of all firms with DEA scores of 0.6 or above, indicating that firms in this group felt that they faced more flexible regulations. There were 96 firms in our sample for this group. The second group comprised all the remaining firms 35 with DEA scores below 0.6. The choice of the cut off value of 0.6 has been made to ensure a minimum 30 sample size for the two regressions to ensure that normality assumptions of regression are satisfied (Anderson et al., 2002).

4.3 Factor analysis

We used factor analysis to measure our two constructs – innovation and financial performance. Results are available in Table 4. All the measures had high loadings (above 0.90, which are well above the minimum threshold of 0.5) on their corresponding constructs. Reliability of the constructs was measured by Cronbach's alpha and Composite Reliability. A Cronbach's alpha or Composite Reliability of 0.65 or higher was used as an acceptable value for internal consistency of the measures (Hair et al., 1998). The Cronbach's alpha and composite reliability of the two constructs are well above this threshold. Average variance extracted (AVE) values are also high - well above the recommended minimum value of 50%. These values support the contention that all the factors have adequate reliability. Thus the values shown in Table 4 validate construct validity of all our constructs.

Table 4: Results of factor analysis

Name	Loading	Average Variance Extracted (AVE)	Cronbach's alpha	Composite Reliability
Innovation capability • Prodinno • Procinno	 .910 .910	83%	0.791	0.906
Financial performance • Sales • Markshare	 .957 .957	92%	0.907	0.957

Table 5 reports correlations among the constructs. All correlations are significant at $p<0.01$. The values on diagonals represent square-root of AVE values of the constructs. Since the square-root of AVE of a construct is larger than the correlations in the corresponding row/column, discriminant validity of our constructs has been established (Hair et al., 1998).

Table 5: Summary statistics and correlation coefficients

	Employees	Innovation	Financial performance
Employees	1		
Innovation capability	.369**	0.911 [a]	
Financial performance	.306**	.320**	0.959
Minimum	1	-3.030	-2.727
Maximum	5	1.740	1.484
Mean	2.70	.000	.000
Std. Deviation	1.148	1.000	1.000

** Correlation is significant at the 0.01 level (2-tailed).

[a] Diagonal values for Innovation and Financial performance are square root of AVE (to verify discriminant validity)

4.4 Regression

To control for the potential relationship between firm size and performance, we have included the number of employees reported by firms (using a Likert Scale of 1 (<50) to 5 (>1000)) as a control variable (Brammer and Millington, 2008) in the regression.

Results of the regression model for our hypotheses are shown in Table 6. Financial performance is the dependent variable in the regression. This construct is regressed with the control variable (employees) and the independent variable (innovation capability). As mentioned earlier, we performed this regression for the two DEA groups separately to highlight the impact of flexibility of environmental regulations. Both the regressions are statistically significant as shown by the F-test. R^2 values are relatively low but acceptable as these are similar to the values reported in the literature (e.g., Blind et al., 2006; Sanchez and McKinley, 1988).

Table 6: Regression results (standardised coefficients) for the impact of innovation on financial performance for different categories of flexibility of regulations.

Dependent Variable: Financial performance		
Independent Variables	Firms facing relatively higher levels of flexible regulations (DEA scores >= 0.6)	Firms facing relatively higher levels of inflexible regulations (DEA scores < 0.6)
Employees (control variable)	0.136	0.378**
Innovation capability	0.267***	0.201
R^2	0.119	0.229
R^2 adj	0.100	0.182
F	6.366***	4.890**
Sample size *N*	96	35

*$p < 0.1$; ** $p < 0.05$; *** $p <. 0.01$

The results highlight that innovation is highly significant ($p < 0.001$) in impacting financial performance for firms that feel they face higher levels of flexible regulation, while it is insignificant for firms that feel they face higher levels of inflexible regulations. Hence, these results strongly support both our hypotheses. Innovation capabilities of firms are highly significant in achieving better financial performance when firms face more flexible environmental regulations (Hypothesis 1); when faced with relatively less flexible regulations, firms are not able to exploit their innovation capabilities to achieve a superior financial performance (Hypothesis 2).

It should be noted here that our approach of using DEA along with regression differs from most of regular DEA applications. There are several DEA-regression studies in the literature where a two-stage approach is typically used (e.g., Chowdhury and Zelenyuk, 2016, also see Simar and Wilson, 2007). In this two-stage approach, DEA efficiency is computed in the first stage. Once DEA efficiencies are calculated, these are used in the second stage as dependent variables in regression with a number of independent variables that capture environmental characteristics. However, our paper uses a different approach in that it does not use DEA scores as dependent variables in regression. Our dependent variable is financial performance, which is not based on DEA scores. Independent variable is innovation capability. (Employees are included in the regression as control variable.) DEA scores are used only to group the sample into two categories (firms facing relatively higher levels of flexible regulations and firms facing relatively higher levels of inflexible regulations).

Further, our approach of dealing with environmental regulations differs significantly from the existing DEA literature. While previous studies such as Zhou et al. (2006) have used the ratio of efficiency scores with and without undesirable outputs in the DEA model in order to capture the impact of environmental regulations, our study uses questionnaire measures to capture flexibility of environmental regulations, which is then used to group the sample into two categories.

5 Further discussion

Our study shows an innovative application of DEA in the context of sustainability analysis to capture the flexibility of environmental regulations, and thus helped to shed interesting new lights on the on-going debate in environmental policy. We believe that our results show clear evidence for the significant positive role of innovation on performance when firms face more flexible regulations and for the insignificant role of innovation when faced with inflexible regulations. By doing so, it has helped extend the debate on Porter's hypothesis. We believe that our study has contributed to the literature in at least two different ways: an innovative application of DEA to capture - for the first time - the relative flexibility of environmental regulations based on firms' perceptions, and, the simultaneous consideration of innovation and flexibility to render support to Porter hypothesis.

Porter's famous hypothesis - that environmental regulations need not harm businesses, but can in fact actually benefit them - has created much controversy. It has been widely seized upon by policymakers and heavily criticised by many economists. Numerous statistical work has been done to test whether or not environmental regulations did in fact lead to

improved performance in firms, with some studies highlighting positive (e.g., Russo and Fouts, 1997), negative (e.g., Brammer et al., 2006) and no (e.g., Aras et al., 2010) relationships. The evidence that emerged from this body of work has not been entirely conclusive. It is the contention of this paper that such inconclusive evidence arises because the vast majority of previous work ignores the two important caveats to the Porter hypothesis outlined by Porter and van der Linde (1995). Specifically, Porter and van der Linde (1995) have stated that the relationship is dependent upon two further requirements: flexibility of regulations, and the ability and willingness of regulated firms to innovatively respond in a "dynamic" way.

As highlighted earlier, our research is the first of its kind to study the link between innovation capability and financial performance for firms facing differing levels of flexibility of regulations. Our results compare favourably with previous studies that have made qualitative propositions (e.g., Ramanathan et al., 2016), and related previous quantitative studies (e.g., Majumdar and Marcus, 2001).

6 Managerial implications and conclusions

This study has shown that innovative application of operational research tools such as DEA can help to extend the debate on how flexible regulations help innovative firms achieve better performance. The implications of this result for managers of manufacturing firms reinforce the importance of being innovative, and of responding to regulations with a "dynamic mindset". Rather than just oppose legislation and try to slow its passage, a firm can see positive results if it embraces the regulations and can actually use it as the basis of competitive advantage. Whilst others may struggle merely to comply with the regulations and keep their existing operations in order, the innovative dynamic firm can use it as an opportunity to move into new product markets, move to leaner and greener production processes, which reduce unnecessary energy consumption and material inputs, as well as turning mandatory recycling into a profitable remanufacturing process. But our study has also shown that if regulations are too poorly designed from a business perspective, innovation will not help firms and the regulations will have a penalising effect. So firms and industrial organisations should seek to work with policymakers in pushing for regulations that allow environmental protection efforts to continue but in a way which does not necessarily penalise all businesses.

Our study has highlighted the benefits of intelligent regulatory design, allowing environmental protection to align with a more competitive and innovative manufacturing

industry. In the UK, this idea has formed the backbone of environmental policy in recent years, with much being made of so-called ‘New Environmental Policy Instruments’ (POST 2004). However we note that, as pointed out by Osborn (1997), the current state of UK’s environmental policy is one of old (relatively inflexible) mixed with new (more flexible). A key task for policymakers is to revise older inflexible regulations to bring them into line with the newer thinking on how environmental policies should develop. Businesses should continue to be consulted on the design of new regulations.

Our results provide vital clues to being innovative in meeting the growing environmental demands on firms. A number of recent developments, including the climate change issues to oil spills, are forcing firms to develop innovative ways to deal with environmental concerns. Perhaps one avenue open to managers is to use their existing capabilities, resources and knowledge in improving their operations in order to achieve better environmental and financial performance.

In spite of useful findings, our study can be extended further. We certainly appreciate that there are other variables that might also influence the relationship between financial and environmental performance. As we mentioned earlier, previous equivocal results on the links between environmental regulation and corporate performance have led researchers to believe that the relationship could be more complex. We have attempted to clarify the impact of innovation capabilities and flexible regulations in this study, but there could also be equally important variables affecting this link. For example, the environmental technology portfolio consists of pollution-control technologies and pollution-prevention technologies (Klassen and Whybark, 1999), and more innovative firms would invest more in pollution-prevention rather than pollution-control. The influence of the environmental technology portfolio on the moderating role of innovation could be an interesting piece of research.

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